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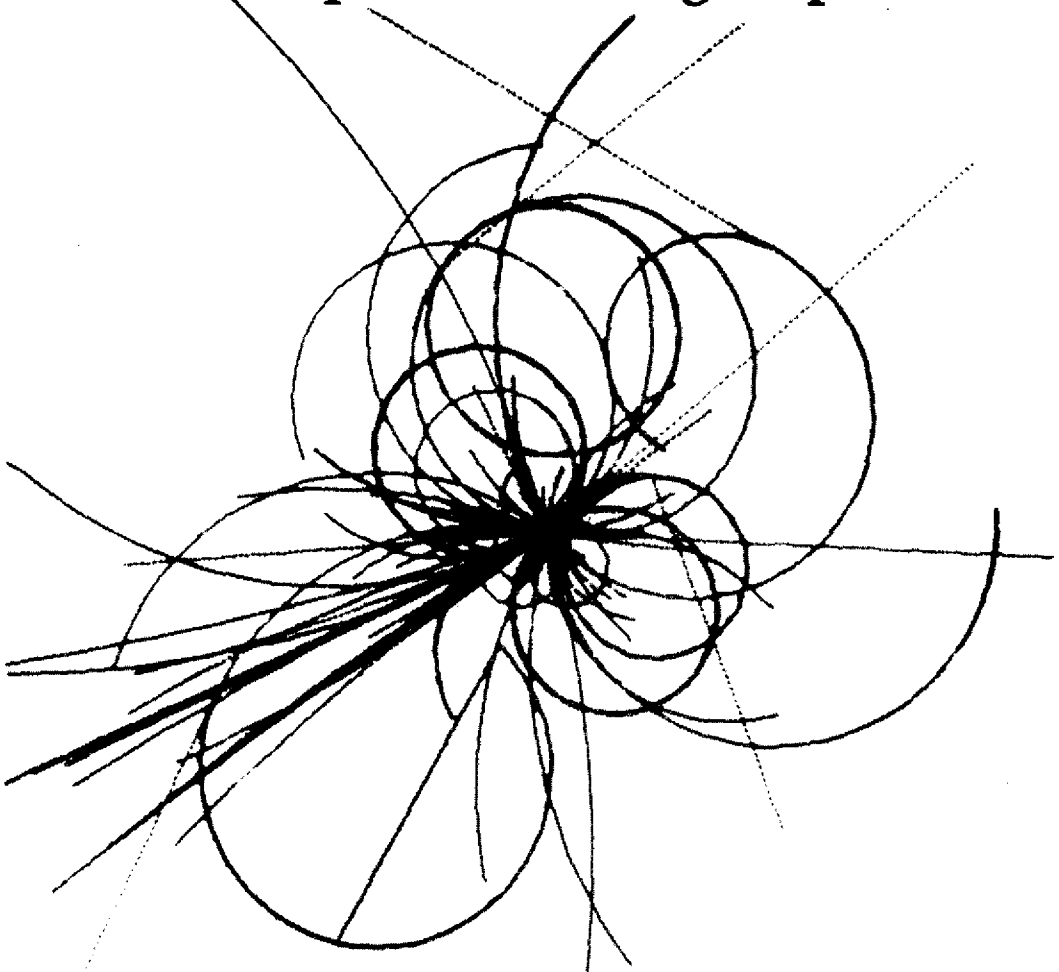
The Superconducting Super Collider



Lattice of the SSC

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Summary

The lattice design of the Superconducting Super Collider Conceptual Design Report is presented. The machine has two vertically separated rings and two diametrically opposite clusters of experimental and utility straight sections. The lattice, characterized by compactness, modularity and optimization of phase intervals between long straight sections, may be flexibly tuned for injection and for different experimental requirements. Cell, experimental and utility straight section, and dispersion suppressor designs are described, as well as chromatic properties for various operational conditions.

Global Structure and Parameters

The lattice has two clusters of straight sections connected by two arcs, which gives the ring an oval shape. Each cluster contains four straight sections with intervening bending sections, while each arc contains 166 regular cells, see Fig. 1. This arrangement places most of the experimental and machine functions in two areas of reasonable size.

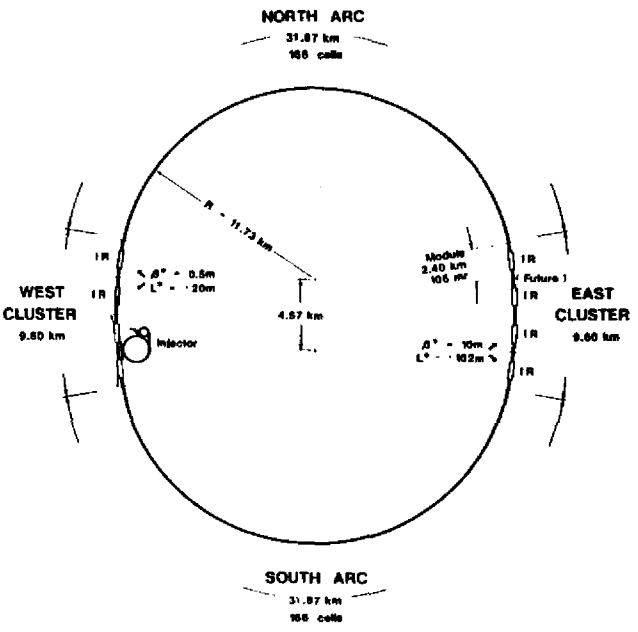

Fig. 1. SSC Ring Layout

Two straight sections in each cluster contain interaction regions (IRs) where the beams collide and cross vertically. Those in the West cluster are called low-β IRs with $\beta^* = 0.5$ m and ± 20 m free space about the interaction points (IPs); those in the East cluster are called medium-β IRs with $\beta^* = 10$ m and ± 102 m free space. In addition, the West cluster contains two utility straight sections for injection, beam abort, and rf, and the East cluster contains two straight sections to be configured in the same way as utility straight sections, but reserved for future development as IRs. Initially the beams will collide and cross (vertically) only in the four IRs, but later crossings will also occur in the two 'future' IRs.

The two rings are separated by 70 cm. The separation is vertical for more efficient use of tunnel space and to simplify bunch synchronization.

Principal parameters of the lattice are shown in Table I. Further details may be found in an SSC note.[1]

Table I Lattice Parameters

circumference	82.944		km
betatron tunes ν_x, ν_y	78.27,	78.28	
chromaticity: coll., inj.	−204,	−106	
momentum compaction	2.227×10^{-4}		
β_{max}, β_{min} in arc	332,	111	m
η_{max}, η_{min} in arc	3.92,	2.36	m
coll. β^* in short, long IRs	0.5,	10	m
inj. β^* in short, long IRs	6.0,	64	m
coll. β_{max} in short, long IRs	7.95,	2.94	km
inj. β_{max} in short, long IRs	688,	506	m
β_{max} in utility straight	1099		m
lengths of short, long IRs	±20,	±102	m
utility center, end drifts	660,	200	m
IP–IP distance, angle	2400,	106	m, mrad
crossing angle (range)	75 –	150	μrad
cells/arc, modules/cluster	166,	4	
cell, module lengths	192,	2400	m
cell phase advance	60°		
short, long IR, utility tunes	3.75, 3.25, 2.25		
magnetic field, gradient	6.60,	212	T, T/m
average, magnetic radius	13.201,	10.108	km
horizontal dipoles per ring	3840		
cell dipole, quad. lengths	16.54,	3.32	m
vertical beamline separation	0.70		m

Symmetry and Modularity

The design has several regularities. Geometrically the ring has reflection symmetry about its NS and EW axes. The arcs are composed of cells, and the clusters are composed of modules that are equivalent in three ways: in plan view they are geometrically identical, their orbit functions are matched to the arc cells, and their betatron phase advances are 90°(mod 180°). This modularity makes the lattice quite flexible and permits future reconfiguration of straight sections.

The eight straight sections are arranged in adjacent, identical pairs. Because of the 90° phase of the modules, these pairs are separated by 90°, which results in cancellation of chromatic

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perturbations.[2,3] In this way, straight sections can be clustered without degrading the beam performance.

Quadrupole polarities follow two rules: vertically adjacent quadrupoles of the two rings have opposite focusing, and for each ring the straight section and dispersion suppressor magnets are symmetrically placed about the straight section centers, with opposite gradients in corresponding quadrupoles.

Arc Cells

A diagram of an arc cell is shown schematically in Fig. 2. Each 96 meter half-cell contains five 16.54 m, 6.6 tesla dipoles (at 20 TeV) with 0.8 m separations and one 3.32 m, 212 T/m quadrupole (magnetic effective lengths). The betatron phase advance is 60°. The two rings have independent, 'one-in-one' magnets except for common magnets near the IPs.

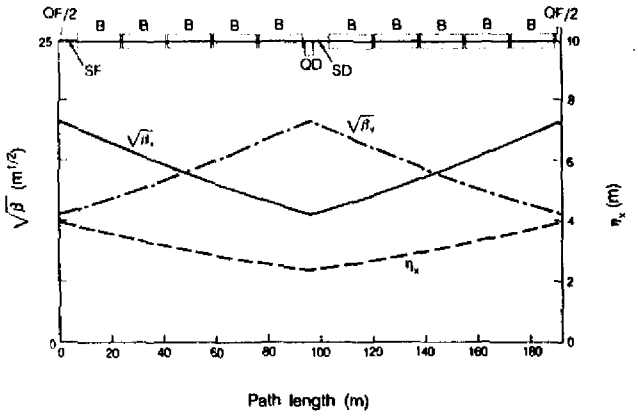

Fig. 2. Arc Cell

A correction spool is placed in a 5.98 m drift on the clockwise side of each quadrupole. Some cells contain two chromaticity correcting sextupoles and others have none. Those with sextupoles occur in 27 contiguous six cell blocks, in order to make the arcs be second order achromats. The two sextupole families in the arcs do all of the chromaticity correction. Similarly, changes in the global tunes are done by two quadrupole trim currents in the arcs, which can produce tune changes of ±2 units.

Cluster Modules

The modules have a generic structure, illustrated in Fig. 3, which shows the module that contains a utility straight section. Every module consists of four blocks: a dispersion suppressor, a (horizontally) straight section, another dispersion suppressor, and a normal 96 meter half-cell. Corresponding suppressors in each module are identical, 576 meters long (the length of three normal cells), and every straight section is twice as long, so that the total module length is 2400 meters. Every straight section and its adjacent suppressors have focussing antisymmetry about the straight section center. There are three types of lattice module, which differ from each other in the focussing and vertical bending structure of their straight sections. Each module is matched to the beta functions and dispersion of the regular cells.

Dispersion Suppressors

Each suppressor, see Fig. 3, consists of three cells identical to regular ones, except that their quadrupoles (and adjacent drifts) have five different lengths but normal gradients and spacing. The five lengths are chosen to fit the cell dispersion and slope values at one end to zero values at the other. The matching is such that the suppressors on the left and right sides of the straight section, which have equal lengths but opposite gradients in corresponding quadrupoles, match the dispersion from zero values in the straight sections to normal values in the cells. Note that the beta functions are perturbed very little from normal cell values. The suppressors are not retuned when the IRs are changed from injection to collision optics. Since the suppressors have the same average curvature as the arcs, they contribute to a compact ring with circumference of about 83 km.

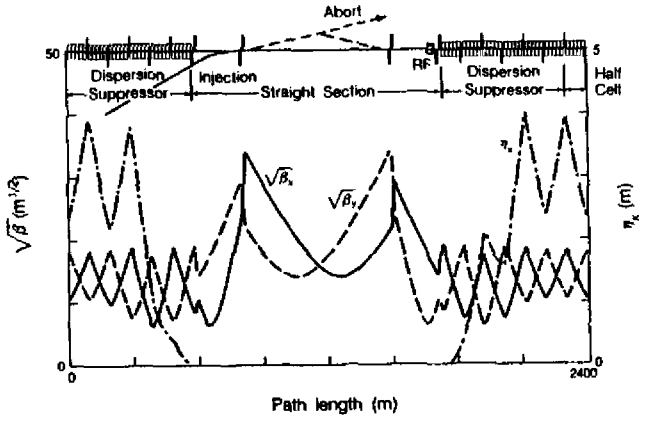

Fig. 3. Utility Module

Straight Sections

The three types of modules are distinguished by their straight sections, utility, low-β, and medium-β.

Utility and Future IR

A utility module is shown in Fig. 3. These straight sections are used for the injection, beam abort and radiofrequency acceleration systems, and the two beamlines do not cross in them. Injection and rf is placed in the 200 m outer drift spaces, and beam abort is done in the 660 m center section. The optics is not changed in the utility straights during the operating cycle. The future IR straights have lattice structures identical to the utilities.

Low-β

These IRs are the sites of experiments at high luminosity, up to $10^{33}\text{cm}^{-2}\text{s}^{-1}$. The two proton beams collide and cross at a very small angle, 75–150 μrad, at the IP at the straight section center (Figs. 4-6). Twenty meter drift spaces are provided for the detectors on either side of the IP, followed by four quadrupoles powered as triplets, common to both beams, that focus the beams to the IP. Beyond the triplets the beams are separated by dipole splitter magnets.

Fig. 4 shows a side view of the insertion. The 70 cm separation between the beamlines is accomplished in two vertical steps with an intervening horizontal section of five quadrupoles where the beamline separation is 35 cm. This section comprises (nearly) two 90°cells, giving it almost an $M = -1$ transfer matrix, which reverses the vertical dispersion caused by the steps. Consequently η_y is matched to zero values at the ends of the steps.

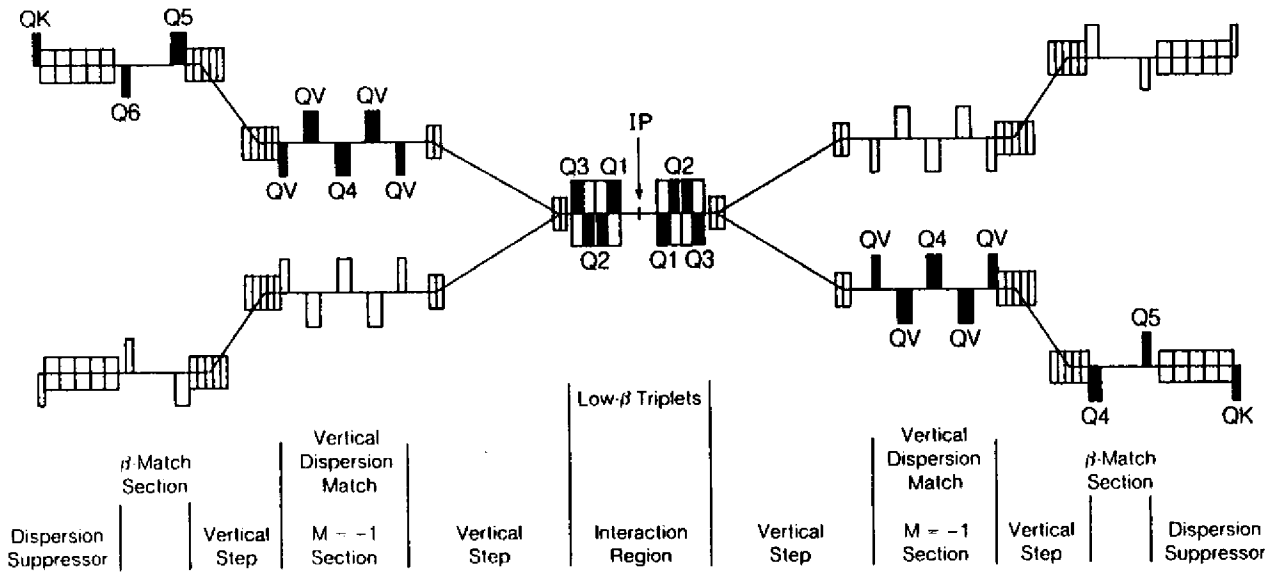

Fig. 4. Side View of Low-β IR Straight Section

Matching of the β functions between the dispersion suppressors and the IP is done with six quadrupole circuits, Q1-Q6. Except for Q4, these quadrupoles are in dispersion free regions. Since the vertical dispersion η_y is zero in the center of Q4, it is only slightly mismatched. The straight section gradients do not exceed those of the cells for any optics, apart from the IR triplets which can go slightly higher, to 235 T/m. Figs. 5 and 6 show the optical functions for collision and injection optics respectivly.

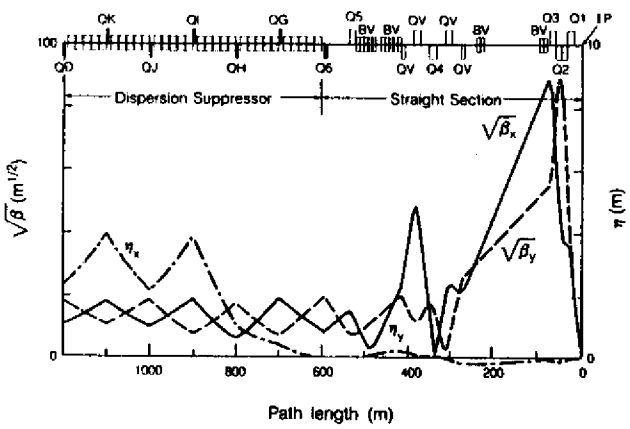

Fig. 5. Low-β Module (left side); Collision Optics

This IR design has the advantages that the beams are separated as close to the IP as possible, which minimizes the long range beam-beam effect and facilitates masking. A disadvantage is that the $M = -1$ region quadrupoles add to sensitivity of the ring to errors, because of their strength and high β value in one of them.

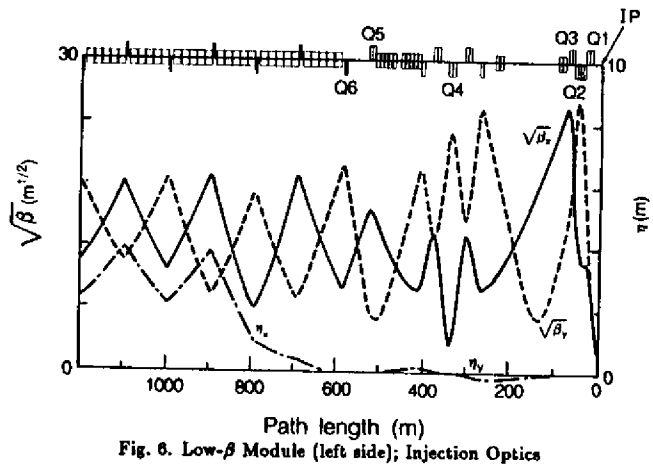

Fig. 6. Low-β Module (left side); Injection Optics

Medium-β

These straight sections, Figure 7, are similar to the low-β ones, but they produce collision β^* values of 10 rather than 0.5 meters, and they have $\pm$ 102 meters of free space rather than $\pm$ 20 meters. This longer drift length is possible because the triplet quadrupoles are shorter and because the first vertical step is made as short as possible. It is acceptable for the beam optics since the higher β^* value limits the maximum βs. The luminosity will be lower than in the low-β IRs by a factor of 20, but the long drift length will permit detection of particles produced at smaller angles.

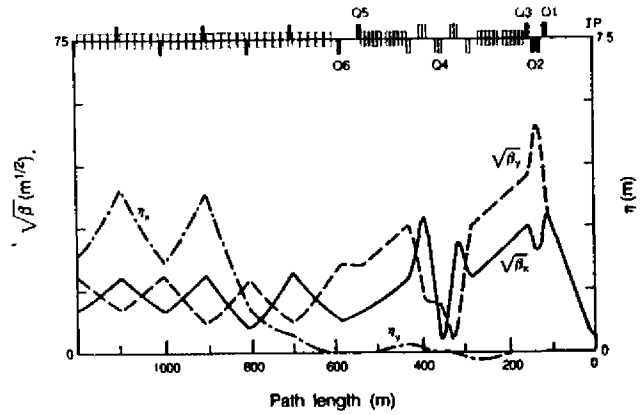

Fig. 7. Medium-β Module (left side); Collision Optics

Optics

Two principal optical configurations are included in the design, an injection optics with β^* values of 6 m and 64 m in the low and medium-β IRs respectivly, and an experimental optics with β^* values of 0.5 m and 10 m in the low and medium-β IRs . It has been found to be feasible to tune β^* separately in the paired IRs between the nominal collision and injection values. Although pairing is thereby violated, this feature is believed to be essential only for the lowest β^* values. The chromatic behavior[4] for various β^* combinations is shown in Fig. 8.

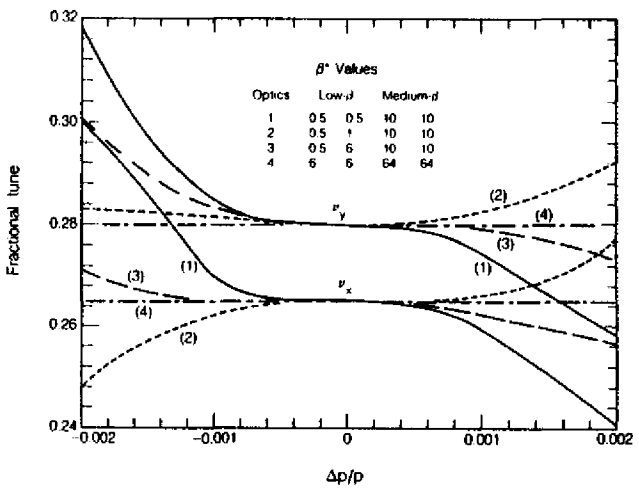

Fig.8. Momentum dependence of the tunes for four combinations of β^* values

Options

Interesting discussions and suggestions for future developments were made at the recent workshop at Snowmass. These included preliminary designs for additional types of IRs to replace the 'future' IRs, such as high-β straights for elastic and diffraction scattering experiments and straight sections with very long spaces about the IPs for forward scattering. Considerable enthusiasm was generated by a bypass design[5] that would enable new IR halls and detectors to be installed along one branch while beams circulated and collided in the IRs of another branch, thus avoiding long shutdowns.

Conclusions

An efficient lattice has been designed for the SSC that groups the main machine and experimental functions into areas of convenient extent without sacrifice of orbit quality.

Acknowledgments

Many people have made contributions to the SSC lattice of the Conceptual Design Report with most of the direct lattice work on this design done by E. Courant, D. Johnson, K. Steffen, and the author. S. Peggs made an alternative IR design with 'late separation' optics. Studies on clustering were made by L. Schachinger using test lattices.[6] Additional studies were done by S. Heifets, D. Neuffer and M. Syphers. Helpful suggestions were made by A. Chao, and M. Harrison gave practical advice on space requirements for the utility straights, power supplies and specifications for special magnets.

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